

PROGRESS ON THE DESIGN AND FABRICATION OF THE MICE SPECTROMETER SOLENOIDS *

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Abstract

The Muon Ionization Cooling Experiment (MICE) will demonstrate ionization cooling in a short section of a realistic cooling channel using a muon beam at Rutherford Appleton Laboratory (RAL) in the UK. A five-coil, superconducting spectrometer solenoid magnet at each end of the cooling channel will provide a 4 T uniform field region for the scintillating fiber tracker within the magnet bore tubes. The tracker modules are used to measure the muon beam emittance as it enters and exits the cooling channel. The cold mass for the 400 mm warm bore magnet consists of two sections: a three-coil spectrometer magnet and a two-coil matching section that matches the uniform field of the solenoid into the MICE cooling channel. The spectrometer solenoid detailed design and analysis has been completed, and the fabrication of the magnets is well under way. The primary features of the spectrometer solenoid magnet and mechanical designs are presented along with a summary of key fabrication issues and photos of the construction.

INTRODUCTION

MICE consists of two spectrometer solenoid systems and the MICE cooling channel [1] which is made up of three absorber focus-coil modules (AFC modules) and two RF and coupling-coil modules (RFCC modules). The muon ionization cooling occurs in the liquid hydrogen absorbers located within the AFC modules [2]. The muons are reaccelerated within the four RF cavities contained in each of the two RFCC modules [3]. The spectrometer solenoid modules couple the muon beam to the adjacent AFC modules and are used to measure the emittance of the muons [4]. The trackers within the spectrometer solenoid modules are five planes of scintillating fibers that measure the position of the particles within the magnet bore volume. An overall view of a three-dimensional CAD model of one of the spectrometer solenoid modules is provided in Figure 1.

SPECTROMETER SOLENOID COILS

The spectrometer solenoid magnet consists of five superconducting coils wound on a common mandrel as shown in Figure 2. The two match coils plus End Coil 1 act like a quadrupole triplet to match the beam in the spectrometer solenoid with the beam in the end AFC modules. The three-coil spectrometer solenoid consists of the two end coils and the center coil. The spectrometer coils generate a uniform field ($\Delta B/B < 3 \times 10^{-3}$) over a

length of 1 meter within a diameter of 0.3 meter. The two match coils combined with the first end coil matches the β in the adjacent AFC module coils with the β in the uniform field region of the spectrometer.

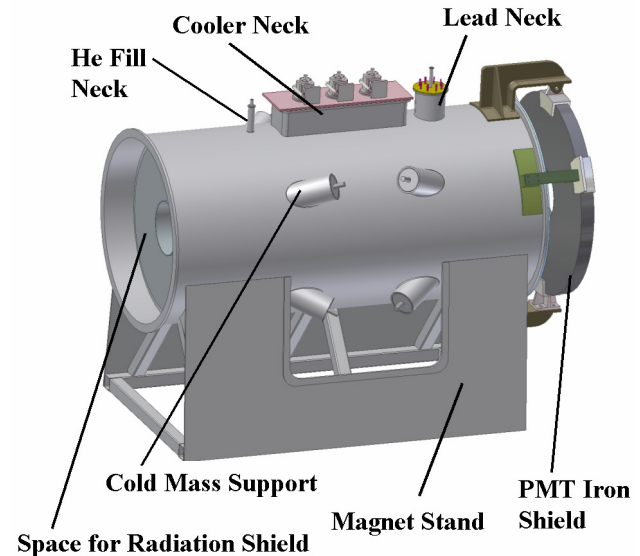


Figure 1: Spectrometer solenoid module 3D CAD image.

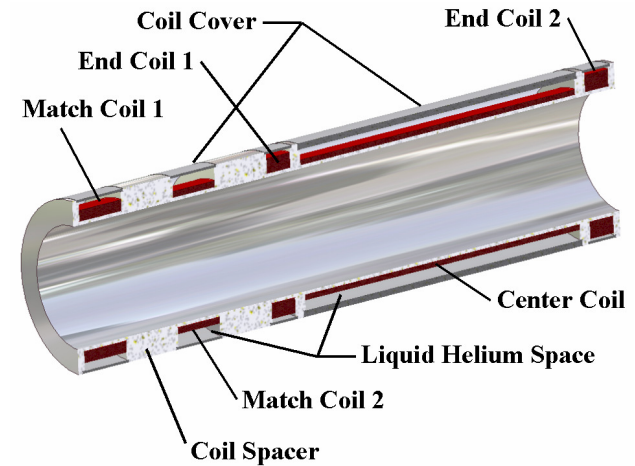


Figure 2: Spectrometer solenoid cold mass assembly.

End Coil 1 serves double duty in that it helps shape the field in the uniform field section of the module as well as assist with the muon beam tuning process. The three spectrometer coils are connected in series and are powered by a single 300 amp power supply. An additional low current supply (up to ± 60 amps) is used to adjust each of the end coils. The small current in End Coil 1, along with Match Coil 1 and Match Coil 2, helps tune the spectrometer solenoid with the MICE cooling channel. The small current in End Coil 2 is used to

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counter the effects of the iron disc at the end of the magnet that serves as a shield for the photo multiplier tubes for one of the detectors that is upstream and downstream of the experiment (see Figure 1). The two match coils will each be separately powered using their own 300 amp power supply. Additional details of the spectrometer solenoid design parameters were presented in a previous publication [5].

The five coils in the spectrometer solenoid are all wound using the same superconducting wire. The superconductor properties are as follows: the insulated conductor dimensions are 1.00 by 1.65 mm, the conductor critical current is 760 A at 5 T and 4.2 K, the conductor Cu to S/C ratio is 3.9 ± 0.4 , the number of filaments is 222 (41 μm in diameter) and the conductor twist pitch is 19 mm. The two spectrometer solenoids will use a total of approximately 110 km of this conductor.

COLD MASS SUPPORTS & HEAT LEAK

Figure 3 provides an overall view of the magnet cryostat and the cold mass supports. The magnet uses a self-centering cold mass support system such that the center of the cold mass remains unchanged as the magnet is cooled from room temperature to 4 K. The supports are designed to carry a total of 500 kN (50 tons) in either longitudinal direction and 50 kN (5 tons) in the radial direction. The cold mass support system must have a large spring constant in the longitudinal direction (>200 MN/m) in order to prevent movement of more than 1.5 mm when MICE is powered. The axis of the solenoid must be co-axial with the warm bore axis to within ± 0.3 mm while the maximum allowable tilt is ± 0.001 radian.

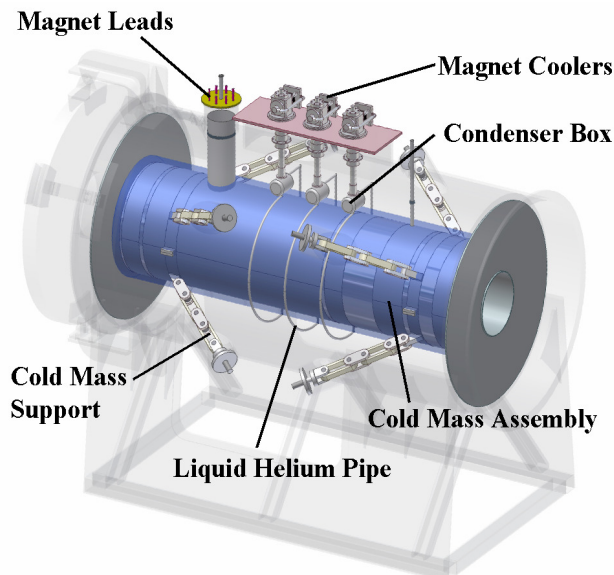


Figure 3: Magnet cold mass and cryostat.

The heat leak into the 50 K and 4 K regions of the magnet is dominated by the loss in the current leads. The tension band supports represent the second largest heat leak into the 4 K region while the second largest heat leak at 50 K is thermal radiation through the MLI. The total heat leak at 4 K and 55 K suggests that each magnet can

be cooled using two 1.5 W (at 4.2 K) cryo-coolers. A third cooler is shown in Figure 3 only as an option.

VACUUM VESSEL AND INTEGRATION WITH MICE COMPONENTS

The overall length of the spectrometer solenoid module is 2923 mm and the length of the magnet vacuum vessel is 2735 mm (Figure 1). At the AFC module end of the module there is a 188 mm long space for a radiation shutter that will shield the scintillating fiber detectors in the magnet bore from the electrons and gamma radiation that comes from the RF cavities as they are conditioned. The total shield thickness is equivalent to 50 mm of lead. The AFC end of the tracker module connects to the AFC module by means of a bellows and load carrying studs. There is a thin window at the AFC end of the magnet so that the scintillating fiber tracker can be operated in a helium atmosphere.

The stand shown in Figure 1 is designed to carry the magnetic forces acting on the coils (up to 50 tons in the longitudinal direction) to the floor of the experiment hall. Because the spectrometer solenoid module vacuum vessel is the same diameter as the AFC module vacuum vessel, the forces carried by the AFC module coils can easily be transmitted to the spectrometer stand as well.

An iron plate shields the photo multiplier tubes (PMT) from the magnetic field generated by the spectrometer magnet (Figure 1). Between the iron shield and the end of the magnet cryostat (in a space of about 250 mm) is a patch panel that carries the light fibers from the scintillating fiber detector to the readout device. In the upstream tracker solenoid is a diffuser system that produces a muon beam with the desired input emittance.

MAGNET FABRICATION

The spectrometer solenoids to be used for the MICE project are currently being fabricated by a qualified vendor under a build-to-spec agreement. Physicists and engineers working on the MICE design developed a preliminary concept for the spectrometer solenoids which is described in a detailed specification that includes all requirements and system parameters. A pre-qualified group of superconducting magnet manufacturers was solicited for bids which were assessed based both on responsiveness to the specification and on price. The superconducting wire, cryo-coolers and power supplies for the magnets were specified and are being provided by the MICE project.

The vendor that was awarded the spectrometer solenoid contract developed a detailed design based on the requirements and guidelines set forth by the specification. The design was subsequently reviewed and approved by a panel consisting of members of the MICE collaboration.

The fabrication of the first spectrometer solenoid magnet is well under way and is expected to be completed before the end of CY 2007. The winding of the 5-coil assembly for the first magnet is nearly complete (see Figure 4). The coils were wound using a wet winding

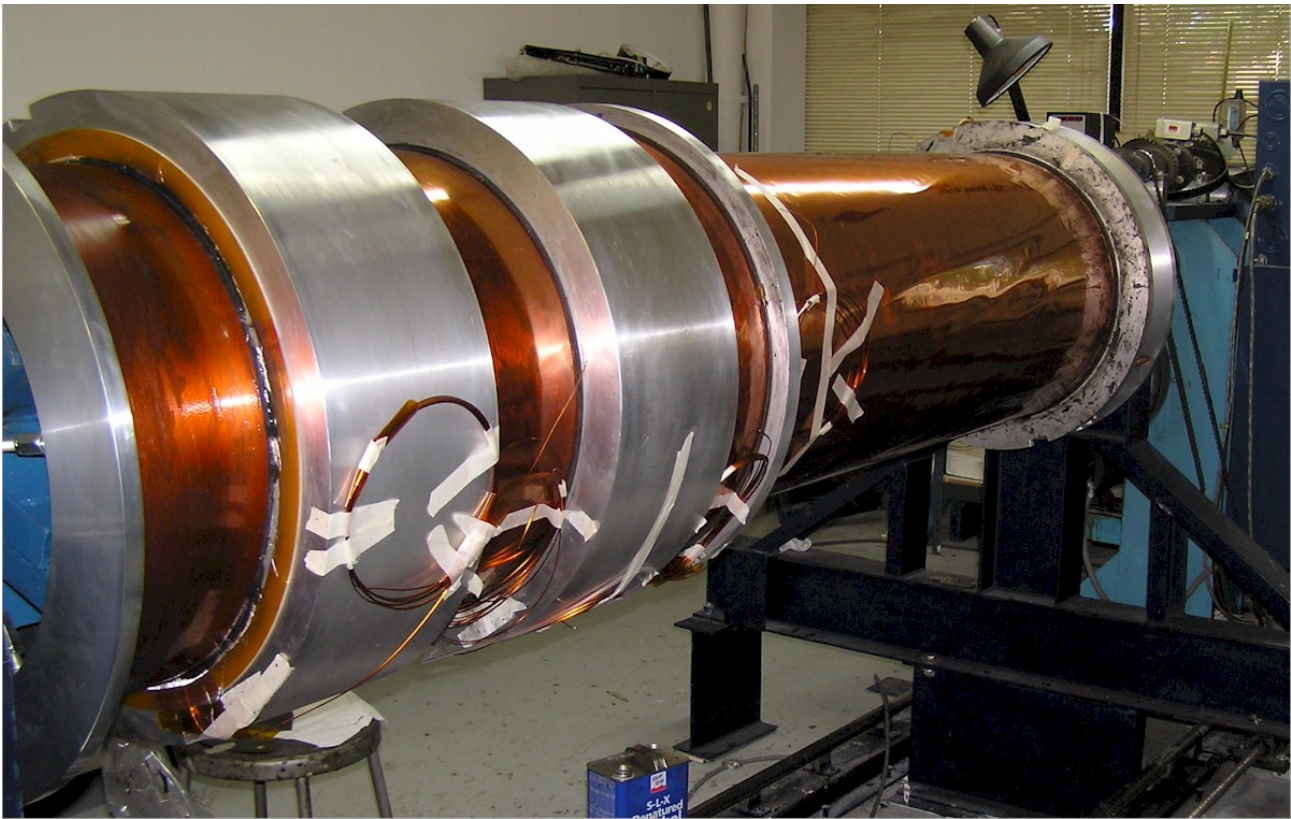


Figure 4: Winding progress on the first 5-coil spectrometer solenoid magnet (4 coils nearly complete).

process. Upcoming steps include the winding of banding around the outside diameter of the coils for support, installation of a passive quench protection system and welding of cover plates to the coil forming mandrel to create the helium vessel and complete the cold mass.

The fabrication of the magnet cold mass supports is also nearing completion. Each of the eight sets of supports will consist of two pairs of wound fiber/epoxy, racetrack shaped bands capable of carrying the required load while minimizing the heat leak. The support band pairs are arranged in parallel to maximize the strength of the assembly. The two pairs of parallel bands are used such that one end of the supports is maintained at 4 K (at the cold mass), an intermediate point is at 50 K (at the thermal shield) and the other end is at 300 K (the room temperature end). A preliminary fit check of some of the parts making up a cold mass support assembly is shown in the photograph in Figure 5.



Figure 5: Cold mass support preliminary fit check.

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